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SYSTEMS ENGINEERING RESEARCH REPORT 81-4

METHODOLOGICAL CONSIDERATIONS IN THE DESIGN OF LARGE SCALE SYSTEMS ENGINEERING PROCESSES

Andrew P. Sage

Supported by:

Engineering Psychology Programs
Office of Naval Research
ONR Contract Number N0014-80-C-0542
Work Unit Number NR-197-065

February 1981

SCHOOL OF ENGINEERING AND APPLIED SCIENCE

DEPARTMENT OF ENGINEERING SCIENCE AND SYSTEMS

UNIVERSITY OF VIRGINIA
CHARLOTTESVILLE, VIRGINIA 22901

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: SE-81-4

2. GOVT ACCESSION NO.: AD-A096 872

3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): METHODOLOGICAL CONSIDERATIONS IN THE DESIGN OF LARGE SCALE SYSTEMS ENGINEERING PROCESSES.

5. TYPE OF REPORT & PERIOD COVERED: Research Report

6. PERFORMING ORG. REPORT NUMBER:

7. AUTHOR(s): Andrew P. Sage

8. CONTRACT OR GRANT NUMBER(s): N00014-80-C-0542

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Department of Engineering Science and Systems
University of Virginia
Charlottesville, Virginia 22901

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: NR-197-065

11. CONTROLLING OFFICE NAME AND ADDRESS:
Engr. Psychology Programs
Department of the Navy. Office of Naval Research
Arlington, Virginia 22217

12. REPORT DATE: February 1, 1981

13. NUMBER OF PAGES:

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report):

Approved for Public Release, Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):

18. SUPPLEMENTARY NOTES:

None

19. KEY WORDS (Continue on reverse side if necessary and identify by block number):

decision support system
systems design
systems methodology
systems management
information systems

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

This paper discusses some methodological considerations in the design of large scale systems engineering processes. We begin our effort by providing several definitions of systems engineering. There are a number of impediments to the resolution of large scale issues in the public and private sectors and it is important that designers of appropriate and useful systems be aware of these. Following a discussion of these impediments, we present a structure describing the systems engineering process. This is used to motivate

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discussion of the functional considerations involved in a systemic process: systems science and operations research, systems methodology and design, and systems management. A brief discussion of methods for formulation, analysis and interpretation is followed by a discussion of systems management and the associated use of human judgment for the design of systemic processes. We believe the contingency task structure of systems management to be an especially useful guideline for the design of information systems for planning and decision support. We give a number of reasons supporting this belief and present a model for information acquisition and information evaluation based on our contingency task structure. A discussion of systems engineering in the political process and implications for professional practice is followed by delineation of the many potential benefits of the systems process.

METHODOLOGICAL CONSIDERATIONS IN THE DESIGN OF LARGE SCALE SYSTEMS ENGINEERING PROCESSES

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ABSTRACT

This paper discusses some methodological considerations in the design of large scale systems engineering processes. We begin our effort by providing several definitions of systems engineering. There are a number of impediments to the resolution of large scale issues in the public and private sectors and it is important that designers of appropriate and useful systems be aware of these. Following a discussion of these impediments, we present a structure describing the systems engineering process. This is used to motivate discussion of the functional considerations involved in a systemic process: systems science and operations research, systems methodology and design, and systems management. A brief discussion of methods for formulation, analysis and interpretation is followed by a discussion of systems management and the associated use of human judgment for the design of systemic processes. We believe the contingency task structure of systems management to be an especially useful guideline for the design of information systems for planning and decision support. We give a number of reasons supporting this belief and present a model for information acquisition and information evaluation based on our contingency task structure. A discussion of systems engineering in the political process and implications for professional practice is followed by delineation of the many potential benefits of the systems process.

1. Definitions, Requirements for and Impediments to the Use of Systems Engineering.

Systems engineering is management technology. Technology is the result of, and represents the totality of the organization, application, and delivery of scientific knowledge for the presumed enhancement of society. Management involves the interaction of the organization with the environment. Consequently, management technology involves the interaction of science, the organization, and the environment. Figure 1 illustrates these conceptual interactions.

We may continue our discussion and definition of systems engineering by indicating one possible structural definition. Systems engineering is management technology to assist and support policymaking, planning, decisionmaking, resource allocation, or action deployment. It accomplishes this by quantitative and qualitative *formulation*, *analysis and interpretation* of the impacts of action alternatives upon the needs perspectives, the institutional perspectives, and the value perspectives of stakeholders.

The key words in this definition are formulation, analysis and interpretation. In fact, all of systems engineering can be thought of as consisting of formulation, analysis, and interpretation. These are the components comprising a framework for systems methodology and design. For successful use of the systems approach, these efforts must be assisted or supported by appropriate methods from system science and operations research. And these efforts must support proper systems management considerations which involve human judgment if we are to evolve truly useful systemic processes. Systems science and operations research, systems methodology and design, and systems management are the functional components of systems engineering.

Problems in modern society involve many considerations and perspectives including:

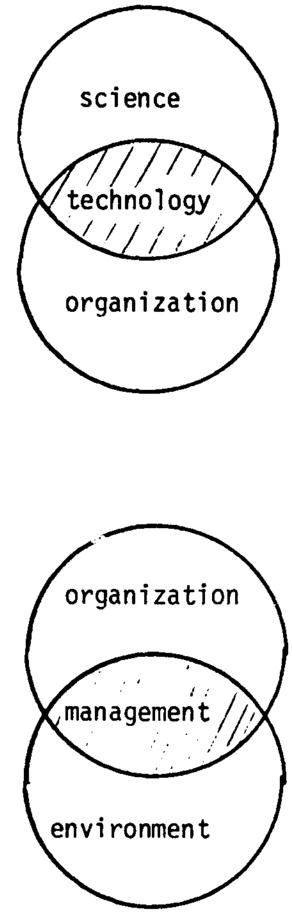
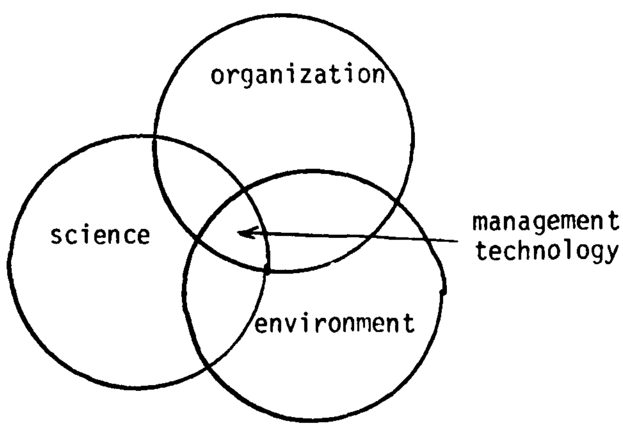


Figure 1. Systems Engineering as Management Technology



- technological considerations
- economic considerations
- legal considerations including questions of patent practices and rights, taxation, and regulation
- managerial considerations, including questions involving innovation and entrepreneurship
- political considerations
- social considerations, including questions of equity, welfare, and harmony
- cultural considerations, involving questions of human values and attitudes
- professional, trade, and intellectual considerations; including the roles of unions and professional organizations
- ethical (and religious) considerations
- environmental considerations
- *military considerations*

All of these considerations generally interact and more often than not the interaction is strong. It is the interaction of many considerations and their perspectives that leads us to call an issue or system a large scale issue, or large scale system.

In order to resolve large scale and complex problems, or manage large systems, we must be able to deal with contemporary issues that involve and require:

a) many considerations and interrelations,

b) many different and perhaps controversial value judgments,

c) knowledge from several disciplines,

d) risks and uncertainties involving future events which are difficult to predict,

e) fragmented decisionmaking structures,

f) needs perspectives and value perspectives as well as technology perspectives,

g) resolution of issues at the level of institutions and values as well as at the level of symptoms.

To be truly useful, the professional practice of systems engineering must be such as to enable the development of adjuvants for management support that allow clients to cope with multifarious large scale issues with these characteristics. But, there are many opportunities for systems engineering failures. Among the causative factors potentially impeding success of the systems method are:

1. over-reliance upon a specific analytical tool strongly advocated by a particular group,
2. consideration of perceived problem resolution only at the level of symptoms,
3. failure to develop and apply an appropriate methodology for problem resolution that will allow:
   a. identification of major pertinent issue formulation elements
   b. identification and exposure of interactions among steps of the problem solution procedure
   c. utilization of policy structure situation models as an inherent and integral part of the systems approach,
4. failure to involve the client, to the extent necessary, in the development of problem resolution alternatives and systemic aids to problem resolution,
5. failure to consider the effects of cognitive heuristics, cognitive biases, and value incoherencies on formulation, analysis, and interpretation of problem resolution alternatives,

6. failure to correlate the systemic process with the cognitive style and behavioral constraints of the client.

Proper use of innovative technologies is capable of improving the human condition. And systems engineering is, itself, a management technology. It is especially important to note that application of technology to large scale problems must consider three levels: symptoms, institutions, and values; or we will continually be confronted with technological solutions looking for problems. Thus successful use of systems engineering will necessarily involve institutional and value considerations. Institutional and value considerations are vital, as they affect the design of systemic processes and because they affect the successful deployment of technologies. To maximize usefulness of appropriate technologies, it is necessary to use methodologies for the design of systemic processes that will allow us to consider need perspectives and value perspectives as well as technology perspectives in the formulation, analysis, and interpretation of large scale issues.

Methodology is sometimes a misused word, even in systems engineering. As we use it, a methodology is an open set of procedures for problem solving. Consequently, a methodology involves a set of methods, a set of activities, and a set of relations between the methods and the activities. To use a methodology we must have an appropriate set of methods. These are the methods provided by systems science and operations research. They include a variety of qualitative and quantitative approaches from a number of disciplines. Associated with a methodology is a structured framework into which particular methods are associated for resolution of a specific issue. Figure 2 indicates how the three step framework of formulation, analysis, and interpretation may be disaggregated into seven supporting steps. These steps typically occur at each of a number of

phases in the typical system life cycle, or in a typical process design effort.

Our continued discussion of systems engineering and systems engineering methodology will be assisted by the provision of a structural, a purposeful, and a functional definition of systems engineering. Table 1 presents these three definitions.

Each of these definitions is important for our discussions here. The functional definition of systems engineering says that we will be concerned with the mathematical and behavioral theory of systems. This we will call systems science and operations research. Also, it says that we will be concerned with a combination of these theories. We will denote the effort to obtain this combination systems methodology and design. Finally, the definition says that we will accomplish this in a useful and appropriate setting. We will use the term systems management to refer to the cognitive tasks necessary to produce a useful process from a systems methodology and design study. The product of this is an appropriate combination of systems science and operations research methods that is used, with appropriate leadership, to resolve issues.

The structural definition tells us that we are concerned with a framework for problem resolution that consists of three fundamental steps:

issue formulation

issue analysis

issue interpretation

With this must be associated an awareness of:

. appropriate methods (systems science and operations research)

. the cognitive process level including human judgment (systems management)

Thus the three functional components of systems engineering are each necessary

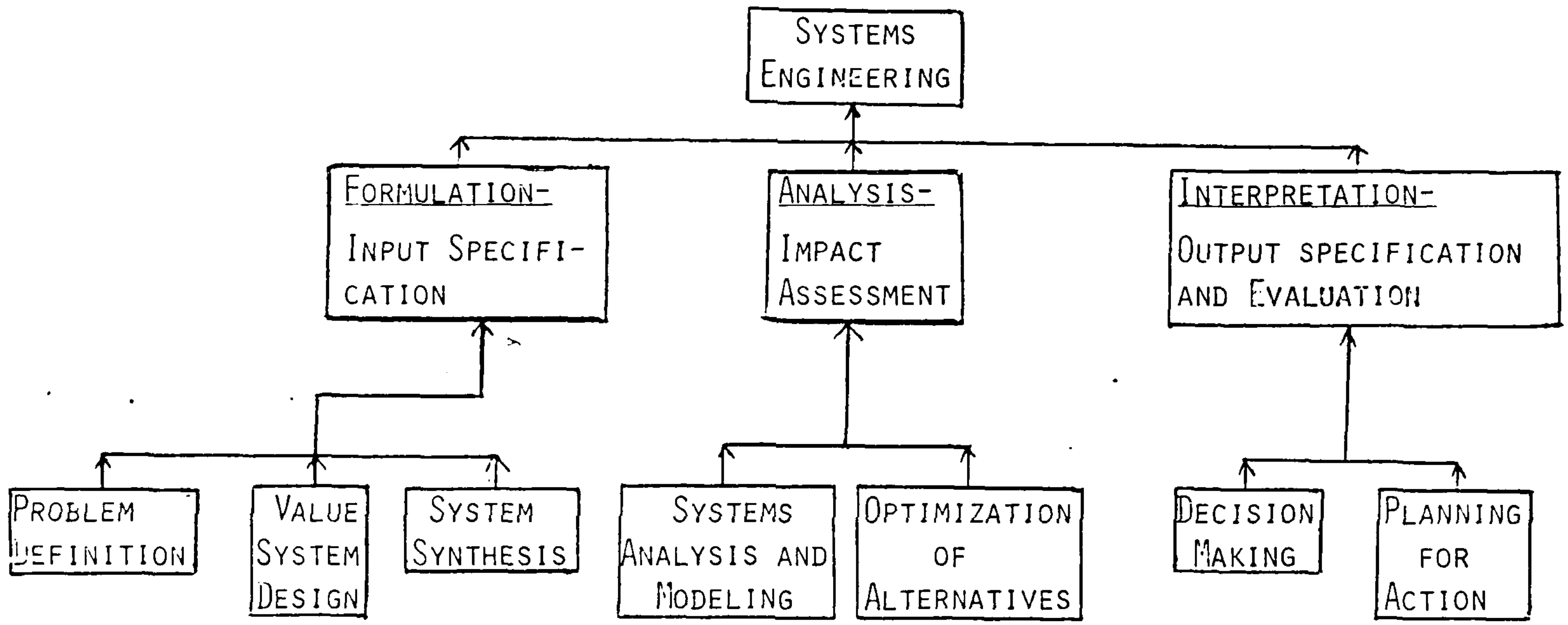


Figure 2. A three step and a seven step framework for systems engineering

STRUCTURE

SYSTEMS ENGINEERING IS MANAGEMENT TECHNOLOGY TO ASSIST CLIENTS THROUGH THE FORMULATION, ANALYSIS, AND INTERPRETATION OF THE IMPACTS OF PROPOSED POLICIES, CONTROLS, OR COMPLETE SYSTEMS UPON THE NEED PERSPECTIVES, INSTITUTIONAL PERSPECTIVES, AND VALUE PERSPECTIVES OF STAKEHOLDERS TO ISSUES UNDER CONSIDERATION.

FUNCTION

SYSTEMS ENGINEERING IS AN APPROPRIATE COMBINATION OF THE MATHEMATICAL THEORY OF SYSTEMS AND BEHAVIORAL THEORY, IN A USEFUL SETTING APPROPRIATE FOR THE RESOLUTION OF REAL WORLD PROBLEMS, OFTEN OF LARGE SCALE AND SCOPE.

PURPOSE

THE PURPOSE OF SYSTEMS ENGINEERING IS TO DEVELOP POLICIES FOR MANAGEMENT, DIRECTION, CONTROL AND REGULATION ACTIVITIES RELATIVE TO FORECASTING PLANNING, DEVELOPMENT, PRODUCTION AND OPERATION OF TOTAL SYSTEMS TO MAINTAIN OVERALL INTEGRITY AND INTEGRATION AS RELATED TO PERFORMANCE AND RELIABILITY.

Table 1. Definitions of Systems Engineering

Within these functional components we have systems science and operations research, systems methodology and design, and systems management. Figure 3 shows a conceptual model of the complete systems engineering process. We will return to a discussion of this conceptual model, in which we will place particular emphasis upon the cognitive process level of systems management concerns, in the sequel.

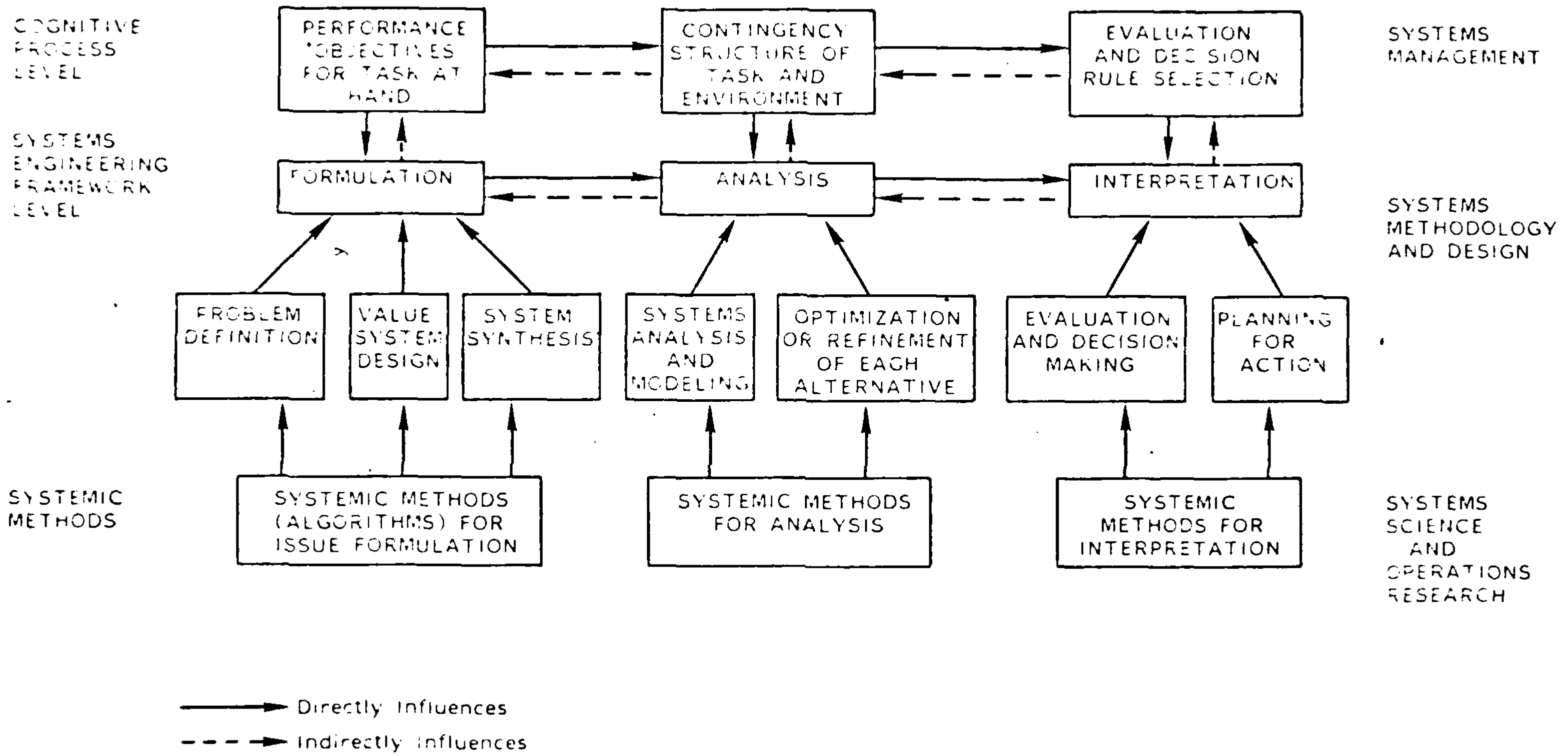


Figure 3. Structure of the Systems Engineering Process in terms of its Funtional Components; Systems Science and Operations Research, Systems Methodology and Design, and Systems Management

2. Systems Engineering Framework and Methods

2.1 Formulation

The formulation step of systems engineering is vital since it is this step which results in the identification of elements for systems engineering studies. It is convenient to discuss issue formulation in terms of the three component steps:

a) problem definition

b) value system design

c) system synthesis

Several of the methods that are particularly helpful in the identification of issue formulation elements are based on principles of collective inquiry in which a group of interested and motivated people is brought together to stimulate each other's creativity in generating elements. We may distinguish two groups of collective inquiry modeling methods:

a. Brainwriting, Brainstorming, Synectics, Nominal Group Technique, and Charette.

These approaches typically require a few hours of time, a group of knowledgeable people gathered in one place, and a group leader or facilitator. Brainwriting is typically better than Brainstorming in reducing the influence of dominant individuals. Both methods can be very productive: 50-150 ideas or elements might be generated in less than one hour. Synectics, based on problem analogies, might be very appropriate if there is a need for truly unconventional, innovative ideas. Considerable experience with the method is a requirement, however, particularly for the group leader. The Nominal Group Tech-

nique is based on a sequence of idea generation, discussion, and prioritization. It can be very useful when an initial screening of a large number of ideas or elements is needed. Charette offers a conference or workshop type format for generation and discussion of ideas and/or elements.

b. Questionnaires, Survey, and DELPHI

These three methods of collective inquiry modeling do not require the group of participants to gather at one place and time, but they typically take more time to achieve results than the first group of methods. In Questionnaires and Surveys, a usually large number of participants is asked, on an individual basis, for ideas or opinions, which are then processed to achieve an overall result. There is no interaction among participants. DELPHI usually provides for written interaction among participants in several rounds. Results of previous rounds are fed back to participants, and they are asked to comment, revise their views as desired, etc. A DELPHI can be very instructive, but usually takes several weeks or months to complete.

Use of most structuring methods, in addition to leading to greater clarity of the problem formulation elements, will typically lead also to identification of new elements and revision of element definitions. Most structuring methods contain an analytical component, and they may, therefore, be more properly labeled as analysis methods. The following element structuring aids are among the many modeling aids available:

- Interaction Matrices. These may be useful to identify clusters of closely related elements in a large set, in which case we have a self interaction

matrix; or to structure and identify the couplings between elements of different sets, for example objectives and alternatives. In this case we produce <u>cross interaction matrices</u> such as shown in Figure 4. Interaction matrices are useful for initial, comprehensive exploration of sets of elements. Learning about problem interrelationships during the process of constructing an interaction matrix is a major result of use of these matrices.

- <u>Trees</u>. Trees are graphical aids particularly useful to portray hierarchical or branching-type structures. They are excellent for communication, illustration, and clarification. Trees may be useful in all steps and phases of a systems effort.

- <u>Interpretive Structural Modeling (ISM)</u>. ISM is a computer-assisted structuring method designed for collective use. The computer is programmed to perform the more straight-forward bookkeeping tasks, thus allowing the user-group to concentrate on the elements and their relations. ISM is particularly useful to assist a group of people in its efforts to create clarity concerning each individual's perceptions of a set of elements, and to structure the groups' discussion concerning the relationships in the set. ISM has been used to structure objectives, attributes, activities, etc.

- <u>Causal Loop Diagrams</u>. Causal loop diagrams, or influence diagrams, represent graphical pictures of causal interactions between sets of variables. They are particularly helpful to make explicit one's perception of the causes of change in a system, and can serve very well as communication aids.

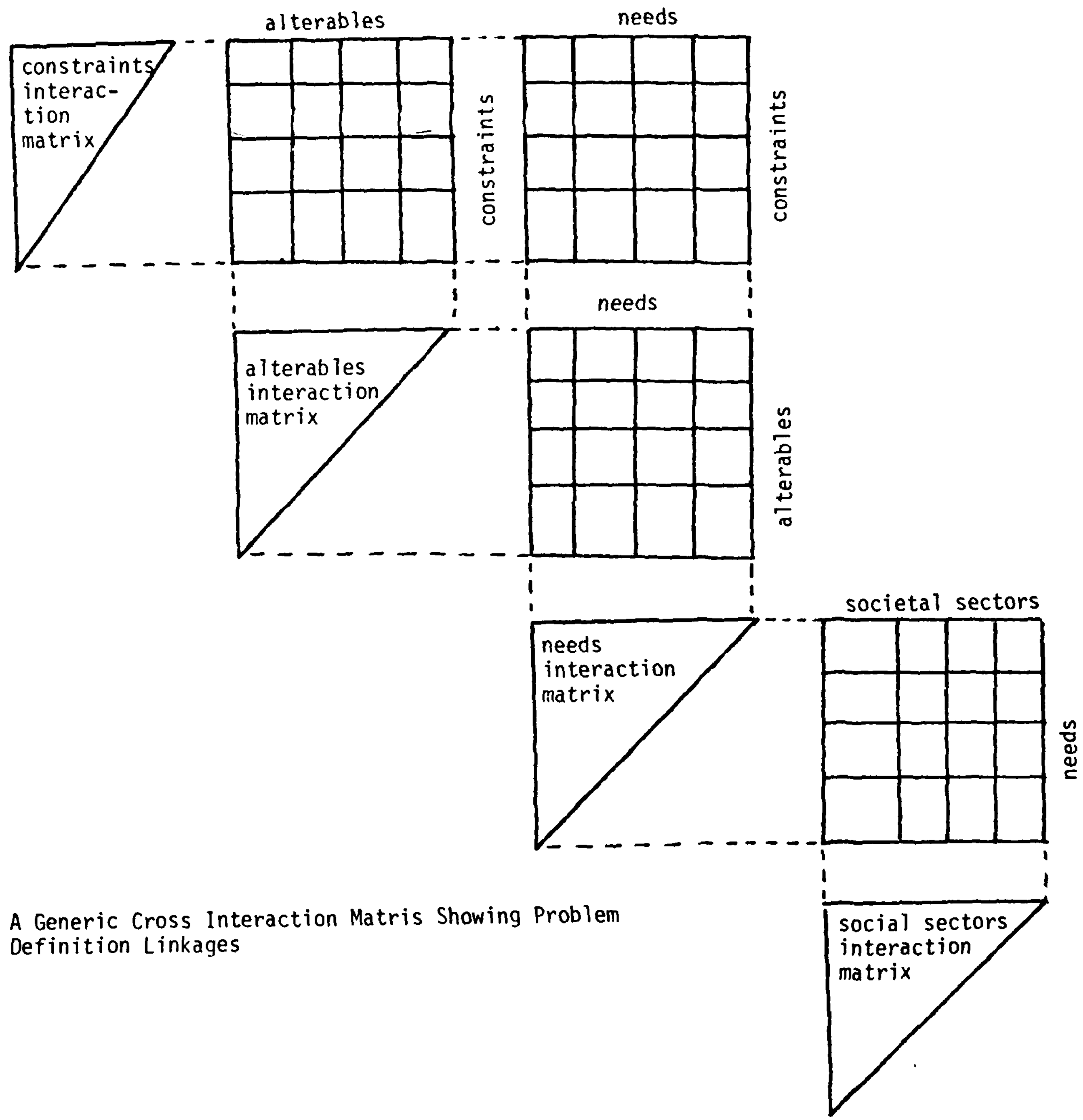


Figure 4. A Generic Cross Interaction Matris Showing Problem Definition Linkages

Two other descriptive methods, potentially useful for issue formulation are:

- System Definition Matrix. The System definition matrix, options profile, decision balance sheet, or checklist, provides a framework for specification of the essential aspects, options, or characteristics of an issue, a plan, a policy, or a proposed or existing system. It can be helpful for the design and specification of alternative policies, designs, or other options or alternatives.
- Scenario Writing. This method is based on narrative and creative descriptions of existing or possible situations or developments. Scenario descriptions can be very helpful for clarification and communication of ideas and obtaining feedback on those ideas. Scenarios may also be helpful in conjunction with various analysis and forecasting methods where they may represent alternative or opposing views.

Clearly, formulation of issues requires creativity. Creativity may be much enhanced through use of a structured systems engineering framework. For example, group meetings, for issue formulation, involve idea formulation, idea analysis and idea interpretation. Figure 5 indicates how the structure of a group meeting may be conceptualized within a systems engineering framework. The framework is especially useful for visualizing the tradeoffs which must be made between allocation of resources for formulation, analysis and interpretation of ideas.

If there is an emphasis on idea formulation, we will likely generate too many ideas to cope with easily. This will lead to a lack of attention to detail. On the other hand if there is a deemphasis on idea formulation, we will typically encourage defensive avoidance through undue efforts to support the

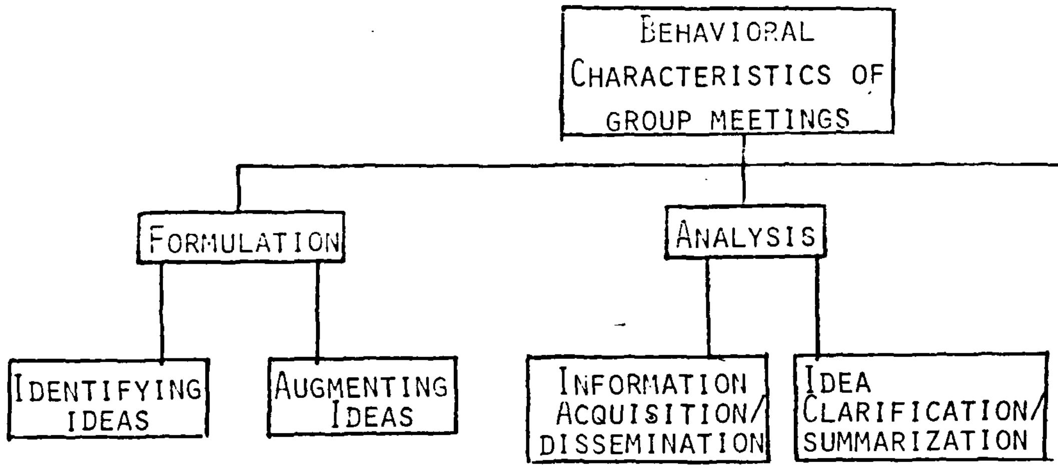


Figure 5. Methodological Framework for Group Meetings

present situation, or a rapid unconflicted change to a new situation. An over emphasis on analysis of ideas is usually very time consuming and results in a meeting which seems to drown in details. Deemphasis on analysis of identified ideas will usually result in disorganized meetings in which hasty, poorly thought out ideas are accepted. Post meeting disagreements concerning the results of the meeting are another often occurring disadvantage. An emphasis on interpretation of ideas will produce a meeting which is emotional and people centered. Misunderstandings will be frequent as issues become entrenched in an adversary-personality centered process. On the other hand, deemphasis on interpretation of ideas results in meetings in which important information is not elicited. Consequently, the meeting is awkward and empty, and routine acceptance of ideas is a likely happening.

A discussion of the three component steps of issue formulation is of value in clarifying the many types of elements identified in this important activity.

Problem definition is an activity in which we work with clients in the identification of needs, constraints, alterables, and possible societal sectors influenced by the other problem definition elements. Often, problem definition efficacy can be enhanced by the construction of a number of alternative hypothetical scenarios into which potential problem definition elements can be imbedded.

Value system design is the transformation of the properties of value into a format amenable to instrumental or extrinsic valuation. We desire to accomplish three tasks in value system design:

- defining objectives and ordering them in a hierarchical structure
- relating the objectives to needs, constraints and alterables
- defining a set of measures by which to determine attainment of the objectives.

Values are especially important and influence and support the entire systems process. They influence the perception of issues and problems. They influence the entire process of judgment. They influence interpersonal relationships among stakeholders to an issue and result in standards for, individual as well as organizational, achievement and success.

Unfortunately, many disagreements among stakeholders to an issue derive from differing, conflicting, and incommensurate values. This appears to be so since stakeholder values are arrived at subjectively and differ markedly. Often, people assume that their values are "normal" and that others should accept or adopt these values uncritically. Also, there is every indication that people are often unaware of many of their own values and associated judgments. Many people have incoherent values that they are incapable of expressing (inchoateness), and have values that change in time without the change being recognized (lability). As a consequence, there are many conflicts between personal values and also among organizational values.

A purpose of value system design is to work with clients and stakeholders to large scale issues such that they are aware of differing and frequently conflicting values, cognizant of personal value systems, and are then able to make decisions with full awareness of their possible impacts and consequences.

System Synthesis is the final step in issue formulation. Its primary concern is with identification of possible alternative policies, activities, options, controls, or complete systems. We desire to answer three questions:

What are alternative approaches for attaining each objective?
How is each alternative approach described?
How do we measure attainment of each alternative approach?

in systems synthesis. We note the emphasis upon measures in both value system design and system synthesis. Extrinsic measurement is needed for proper application of the systems approach. And therein lies a pitfall. For it is easy to sublimate satisfactory attainment of objectives with "high scores" on instru-

mental measures. They are not the same,as proper causality directions have been reversed by the, typically, false, assumption that a high instrumental measure necessarily infers a high degree of objective attainment.

Completion of system synthesis "completes" the initial issue formulation effort. The systems process is an iterative process however, even though we present it, for convenience, in a sequenced fashion beginning with issue formulation and ending with interpretation. Issue formulation elements may be identified at any of the steps of a systems effort and should, in principle, be included in the effort from that point on. Thus, we truly have an iterative process and must consider it as such.

2.2 Analysis

Issue analysis in systems engineering involves forecasting and assessment of the impacts of proposed alternative courses of action. Impact assessment in systems engineering includes: systems analysis and modeling, and optimization and ranking or refinement of alternatives. First, the options or alternatives defined in issue formulation are analyzed to assess the expected impacts of their implementation. Secondly, a refinement or optimization effort is often desirable. This is directed towards refinement or finetuning a viable alternative, and parameters within an alternative, so as to obtain maximum needs satisfaction, within given constraints, from a proposed policy.

Forecasting is an essential ingredient of analysis, or impact forecasting and assessment. There are many problems associated with forecasting in large-scale societal systems. Among these are: uncertainty concerning important future events, uncertainty concerning changes in the laws that attempt to govern society, uncertainty concerning institutional changes, and uncertainty concerning changes in human values. Human behavior will, to a large extent, determine the course of society and hence affect the impacts of pol-

icies. Consequently, the role of the behavioral component of systems, in our analysis efforts, will generally be most important. A great variety of approaches have been designed and used for forecasting and assessment. There are basically two classes of methods that we describe here: expert opinion methods, and modeling and/or simulation methods.

Expert opinion methods are based on the assumption that knowledgeable people will be capable of saying sensible things about the impacts of alternative policies on the system, as a result of their experience with, or insight, into, the issue or problem area. These methods are generally useful. They are particularly appropriate when there are no established theories or data concerning system operation, precluding the use of more precise analytical tools. Among the most prominent expert-opinion based forecasting methods are surveys, and DELPHI. There are, of course, many other ways of asking experts for their opinion; for example hearings, meetings, conferences, etc. A particular problem with expert opinion models is that cognitive bias is wide spread as are value incoherences; and incorporation of bias and coherent values into these models often results in inconsistent and self-contradictory results. There exists a strong need in the forecasting and assessment community to recognize and ameliorate, by appropriate procedures, the effects of cognitive bias and value incoherencies in expert opinion modeling efforts.

Simulation and modeling methods are based on the conceptualization and use of an abstraction or model of the real world which hopefully bahaves in a similar way as the real system. Impacts of policy alternatives are studied in the model, which will hopefully lead to increased insight into real-world

policy impacts. Models are, of necessity, dependent on the value system and the purpose behind utilization of a model. Given the definition of a problem, a value system, and a set of proposed policies, we wish to be able to design a model consisting of relevant elements of these three sets and to determine the results of implementing proposed policies.

There are three essential steps in constructing a model:

1. Determine those issue formulation elements which are most relevant to a particular problem.
2. Determine the structural relationships among these elements.
3. Determine parametric coefficients within the structure.

Most simulation and modeling methods employ the power of mathematical formulations and computers to keep track of many pieces of information at the same time. Two methods in which the power of computer is combined with subjective expert judgments are Cross-Impact Analysis and Workshop Dynamic Models. Typically, experts provide subjective estimates of event probabilities and event interactions. These are processed by a computer to explore their consequences, and fed back to the analysts and thereafter to the experts for further study. The computer derives the resulting behavior of various model elements, over time, giving rise to renewed discussion and revision of assumptions.

Expert judgment is virtually always included in all modeling methods. Scenario writing can be an expert opinion modeling method. But typically this is done in a less direct and explicit way than in DELPHI, Survey, ISM, Cross Impact, or Workshop Dynamic Models. As a result of this, internal inconsistency problems are reduced with those methods based upon mathematical modeling. The following other forecasting methods based on mathematical

modeling and simulation are among those available. In these methods, a structural model is generally formed on the basis of expert opinion and physical or social laws. Available data is then processed to determine parameters within the structure. Unfortunately, these methods are sometimes very data intensive and, therefore, expensive and time consuming to implement.

- Trend Extrapolation/Time Series Forecasting is particularly useful when sufficient data about past and present developments are available, but there is little theory about underlying mechanisms causing change. The method is based on the identification of a mathematical description or structure that will be capable of reproducing the data into the future, typically over the short to medium term.
- Continuous-time Dynamic Simulation is based on postulation and qualification of a causal structure underlying change over time. A computer is used to explore long-range behavior as it follows from the postulated causal structure. The method can be very useful as a learning and qualitative forecasting device, but its application may be rather costly and time consuming.
- Input-Output Analysis has been especially designed for study of equilibrium situations and requirements in economic systems in which many industries are interdependent. Many economic data fit in directly to the method, which is, mathematically, relatively simple, and can handle many details.
- Econometrics is another method mainly applied to economic description and forecasting problems. It is based on both theory and data, with, usually, the main emphasis on specification of structural relations based upon macroeconomic theory and the derivation of unknown parameters in behavioral equations from available economic data.

. Micro-economic Models represent an application of economic theories of firms and consumers who desire to maximize the profit and utility of their production and consumption alternatives.

There are at least three uses to which models may normally be put. Model categories corresponding to these three uses are: descriptive models, predictive or forecasting models, and policy or planning models. Representation and replication of important features of a given problem is the object of a descriptive model. Good descriptive models are of considerable value in that they reveal much about the structure of a complex issue and demonstrate how the issue formulation elements impact and interact with one other. An accurate descriptive model must be structurally and parametrically valid. One of the primary purposes behind constructing a descriptive model is to learn about the impacts of various policy alternatives and, thereby, to forecast and assess the impacts of alternatives.

In building a predictive or forecasting and assessment model, we must be especially concerned with determination of proper cause and effect, or input/output, relationships. If the future is to be predicted with integrity, we must have a method with which to determine exogenous or independent "given" variables accurately and the model structure must be valid and parameters within the structure must be accurately identified. Often, it will not be possible to accurately predict all exogenous variables and, in that case, conditional predictions can be made from scenarios. Consequently models are often used to generate a variety of future scenarios, each a conditional prediction of the future.

Policy or planning models are much more than predictive or forecasting and assessment models, although any policy or planning model is also a

predictive or forecasting model. The outcome from a policy or planning model must ultimately be evaluated in terms of a value system. Policy or planning efforts must not only predict outcomes from implementing alternative policies, but they must also present these outcomes in terms of the value system that is in a form useful and suitable for the alternative ranking, evaluation, and decisionmaking that takes place in the interpretation step of systems engineering.

There exists a number of methods for finetuning, refinement, or optimization of individual specific alternative policies or systems. These are useful to determine the best (in terms of needs satisfaction) control settings or rules of operation in a well-defined quantitatively describable system. A single scalar indicator of performance, or desirability, is typically needed. There are, however, approaches to multiple objective optimization which are based on welfare type optimization concepts. It is these individually optimized policies or systems which are an input to the evaluation and decisionmaking effort in the interpretation step of systems engineering.

Mathematical Programming is used extensively in operations research and analysis practice, for resource allocation under constraints, resolution of planning or scheduling problems, and similar applications. It is particularly useful when the best equilibrium or one-time setting has to be determined for a given policy or system.

Optimum Systems Control addresses the problem of determining the best controls or actions when the system, the controls or actions, the constraints, and the performance index may change over time. A mathematical description of system change is necessary. Optimum Systems Control is particularly suitable for refining controls or parameters in systems in which trade-offs over time play an important part.

Application of the various refinement or optimization methods like these

described here, typically requires significant training and experience on the part of the analyst. The general area of alternative policy optimization is, at this time, far better developed than the other structural areas of systems engineering.

Standards of validity are especially important for analysis methods since the complexity associated with these approaches often makes them difficult to understand by those not well trained in analysis methods. Among possible tests and requirements for model validity and usefulness are the following:

1. accurate reproduction of past behaviors
2. accurate forecast of futures
3. correct prediction of the effects of different controls, designs, or policies
4. correct prediction of changes in a basic mode of system behavior--e.g., sudden increases in the prices of raw materials, simultaneous recession & inflation, social revolution, breakout of war, etc.
5. model contains or does not contain factors believed by "experts" to be of critical significance
6. model accords with or contradicts previous theories or present prejudices
7. assumptions and structure of the model can be explained in a way that is easily understandable by the decisionmakers who in the end will have to use it.

Some of the many characteristics of analysis that are of importance for systemic efforts include the following. Analysis methods:

1. are invaluable for understanding the impacts of proposed policy.

2. lead to consistent results if cognitive bias issues associated with expert forecasting and assessment methods are resolved.

3. may not necessarily lead to correct results since "formulation" may be flawed, perhaps by cognitive bias and value incoherencies.

However, large models and large optimization efforts are often expensive and difficult to understand and interpret. On the other hand, models can help provide a framework for debate. It is important to note that small "back of the envelope" models can be very useful. They have advantages; cost, simplicity, and ease of understanding that large models often lack.

It is very important to distinguish between analysis and interpretation, in systems engineering efforts. Analysis cannot substitute, or will generally be a foolish substitute, for judgment, evaluation, and interpretation as exercised by a well informed decisionmaker. We now turn to the "final" systems engineering step: Issue interpretation.

2.3 Interpretation

The last step, interpretation, of our systems engineering framework involves output specification and evaluation using the information concerning alternative impacts that was determined from the issue formulation elements by means of analysis. It is in this step that we accomplish decision making and planning for action to implement chosen alternatives. The evaluation of alternative actions must, typically, be accomplished and implementation decisions made in an atmosphere of uncertainty. The outcome from any proposed policy is seldom known with certainty. One of the purposes of efforts in the analysis step is to reduce, to the extent possible, uncertainties

associated with the outcomes of proposed policies. Decisionmaking, policy analysis, and planning will often involve a large number of decision-makers who act according to their varied preferences. Often, these decisionmakers will have diverse and conflicting data available to them and the resulting decision situation will be quite fragmented. Further, outcomes resulting from actions can often only be adequately characterized by a large number of incommensurable attributes. Comparison among these attributes, by many stakeholders in an evaluation and choicemaking process, is typically most difficult. Also, inadvertent biases, such for example as those due to a nonconscious ideology, are systematic and prevalent in most unaided cognitive activities. Unaided evaluations, decisions, and judgments are influenced by many heuristic procedures which may lead in, some cases, to very inferior results. It is often quite difficult to disaggregate the valuation associated with policy outcomes from the causal and uncertain relations and events which determine these outcomes. This confounding of values with facts can lead to extreme difficulties in communication as well as choice making. The systems process attempts to reduce these difficulties through a divide and conquer process.

It is important to note that there is a clear and distinct difference between the refinement of individual alternatives, or optimization step of analysis, and the evaluation of sets of refined alternatives. In some cases, refinement of individual alternative policies is not needed in the analysis step. But evaluation of alternatives is always needed; for if there is but a single policy alternative, then there really is no alternative at all. The option to do nothing at all must always be considered as a policy alternative. It is especially important to avoid a large number of cognitive biases, poor

judgment heuristics, and value incoherencies in the activities of evaluation and decisionmaking. The efforts involved in evaluation and choicemaking interact strongly with the efforts in the other steps of the systems process and these are also influenced by cognitive bias, judgment heuristics, and value incoherencies. One of the fundamental tenents of the systems process is that by making the complete issue resolution process as explicit as possible, it is easier to detect and connect these deficiencies than it is in intuitive gestalt processes.

There are a number of methods for evaluation and choicemaking which are of importance. Among these are:

- Decision Analysis which is a very general approach to option evaluation and selection. It involves: identification of action alternatives and possible consequences, identification of the probabilities of these consequences, identification of the valuation placed by the decisionmaker upon these consequences, computation of the expected value of the consequences, aggregating or summarizing these values for all consequences of each action. In doing this we obtain an evaluation of each alternative act and the one with the highest value is the most preferred action or option.
- Worth Assessment and Multi-Attribute Utility Theory has been designed to facilitate comparison and ranking of alternatives with many attributes or characteristics. The relevant attributes are identified, structured, and a weight or relative utility is assigned by the decisionmaker to each basic attribute. The attribute measurements for each alternative are used to compute an overall worth or utility for each attribute. Multi-attribute utility theory allows for various types of worth structures and for the explicit recognition and incorporation

of the decisionmakers attitude towards risk in the utility computations. Worth assessment is a simpler, more straightforward process in which risk considerations are not taken into account. Both methods are very helpful to the decisionmaker in making values and preferences explicit, and making decisions that are consistent with those values.

. Policy Capture (or Social Judgment Theory) has also been designed to assist decisionmakers in making their values explicit, and their decisions consistent with their values. In policy capture, the decisionmaker is asked to rank order a set of alternatives in a gestalt or wholistic fashion. Then, alternative attributes and associated attribute measures are determined by elicitation from the decisionmaker. A mathematical procedure involving regression analysis is used to determine that relative importance weight of each attribute which will lead to a ranking as specified by the decisionmaker. The result is fed back to the decisionmaker who, typically, will express the view that his or her values are different. In an iterative learning process, preference weights and/or overall rankings are modified until the decisionmaker is satisfied with both the weights and the overall alternative ranking.

There are many advantages to formal interpretation efforts. Among these are the following:

1. Developing decision situation models to aid in making the choice-making effort explicit helps one both to identify and to overcome the inadequacies of implicit mental models

2. The decision situation model elements, especially the attributes of the outcomes of alternative actions, remind us of information we need to obtain about alternatives and their outcomes.
3. We avoid such cognitive heuristics as evaluating one alternative on attribute A and another on attribute B.
4. We improve our ability to process information and consequently reduce the possibilities for cognitive bias.
5. We can aggregate facts and values in a prescribed systemic fashion rather than by adopting an agenda dependent or intellect limited approach.
6. We enhance brokerage, facilitation and communication abilities among stakeholders to complex issues.

We strongly believe the reasoning processes supporting rational decisions are capable of explication. Intuitive processes are imperfectly understood. Thus rational decisions are easier to defend and explain than intuitive processes. It should be noted that we refer not only to substantive rationality here, but also to process rationality. Attainment of process rationality will be associated with successful systems management, a topic to which we will soon turn.

Unfortunately there are a number of difficulties which make the interpretation efforts more difficult, than it otherwise might appear to be. Limits on human rationality lead to the use of simple information processing models, thereby producing cognitive bias, and simple decision rules, or poor cognitive heuristics. Use of these simple strategies leads to short run resource savings. But, the resulting decisions are of less than maximum quality. While such decisions might be appropriate for unimportant events in life, such as choosing a movie, they appear inappropriate for decisions

with significant consequences. The use of cognitive heuristics and biases increases with increasing stress. Unfortunately, the decisions associated with significant consequences are those associated with significant stress.

The ingredients leading to good decision making are:

1) quality information and lack of cognitive information processing bias.

2) coherent values

3) a systemic approach to insure appropriate decision rule selection and avoidance of poor cognitive heuristics

4) moderate stress, such as to insure vigilance in the decision making process.

Information is certainly a key ingredient supporting quality decisions. There are 3 basic types of information. These are fundamentally related to the three step framework of systems engineering.

1) Formulation Information

   a) information concerning the problem and associated needs, constraints, and alterables

   b) information concerning the value system

   c) information concerning possible option alternatives

   d) information concerning possible future alternative outcomes states or scenarios

2) Analysis Information

   a) information concerning probabilities of future scenarios

   b) information concerning impacts of alternative options

   c) information concerning the importance of various value criterion or attributes

3) Interpretation Information

a) information concerning evaluation and aggregation of facts and values

b) information concerning implementation

We see that useful and appropriate formulation, analysis, and interpretation of information is one of the most important and vital tasks in systems engineering efforts. For, it is the efficient processing of information by the decision maker that produces effective decisions. A useful definition of information for our purposes is that it is data of value for decision making. The decision making process is influenced by many contingency and environmental influences as indicated in Figure 6. A purpose of management technology is to provide systemic support processes to further enhance efficient decision making as indicated in Figure 7. The design of information systems for planning and decision support is an important task to achieve these ends.

After completion of evaluation and decision making efforts it is generally necessary to become involved in planning for action to implement the chosen alternative option or the next phase of a systems engineering effort. More often than not, it will be necessary to iterate through the steps of systems engineering several times to obtain satisfactory closure upon one or more appropriate action alternatives. Planning for action leads, also, to questions concerning resource allocation, schedules and management plans. There are, of course, a number of methods from systems science and operations research which support determination of schedules and implementation plans. Each of the steps is needed with different focus and emphasis at each phase of a systems effort. These phases depend upon the particular effort under consideration but will typically include such phases as policy and program planning, project planning, system development, etc.

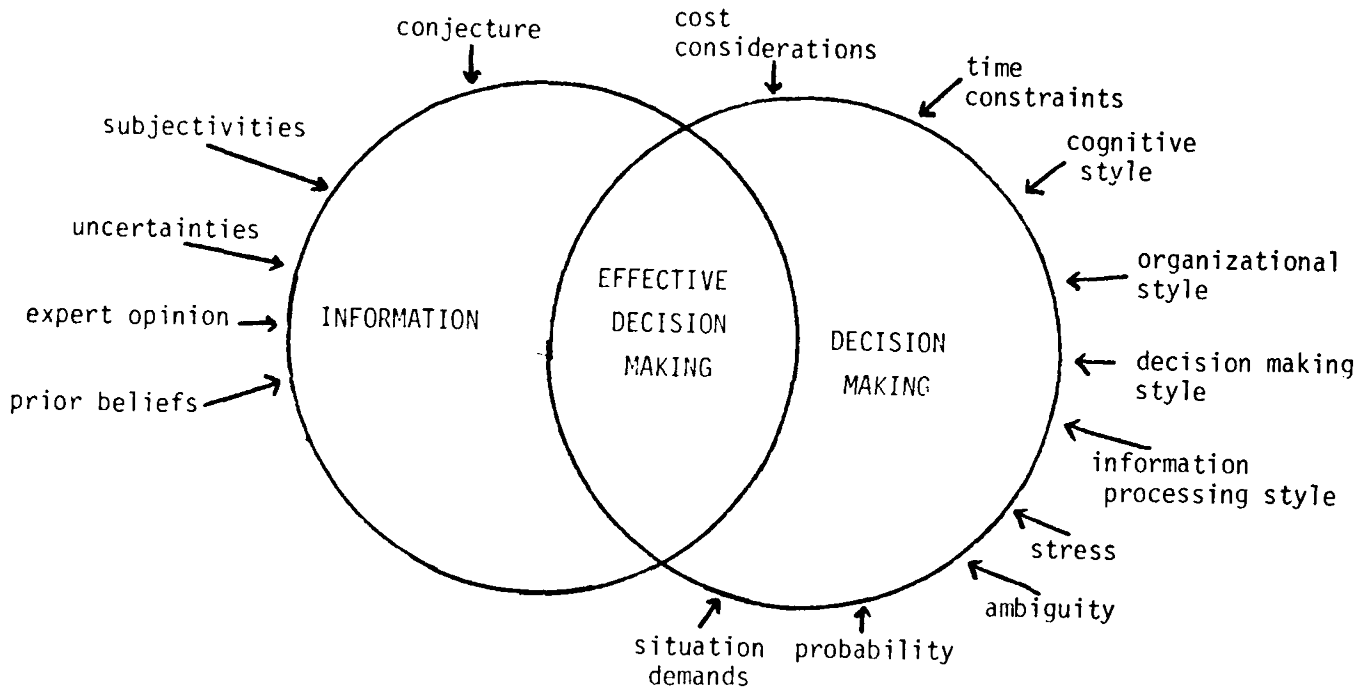


Figure 6. The Role of Information in Effective Decision Making

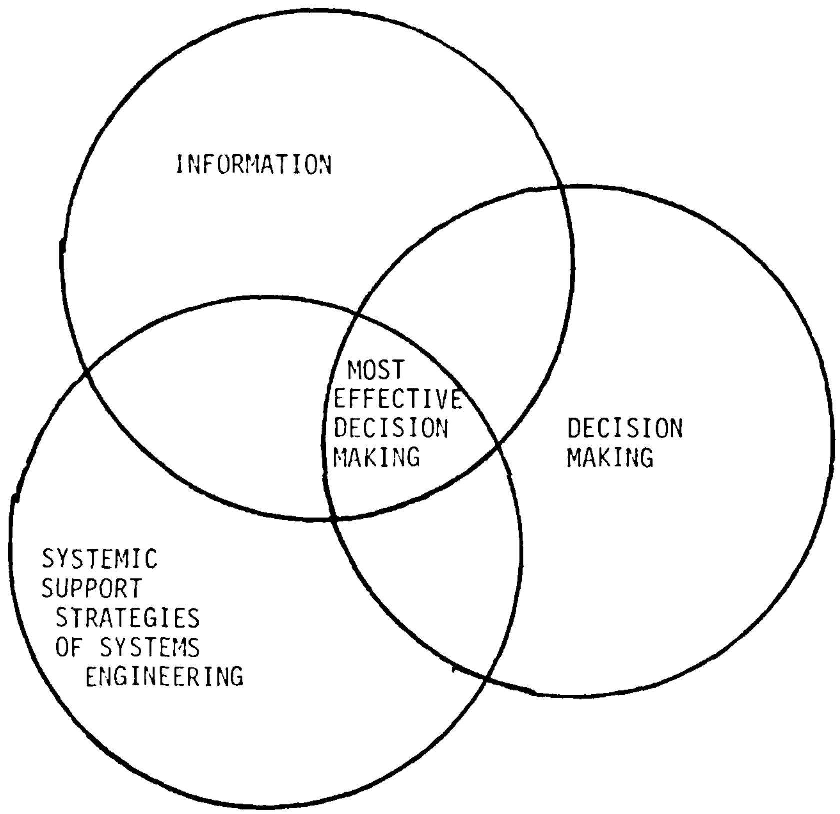


Figure 7. The Role of the Management Technology of Systems Engineering in Providing Support for Efficient Decision Making

3. Systems Management

There are a number of complexities affecting "rational" decision making and we must cope with these in the design of effective systemic processes. The majority of these complexities involve systems management considerations. Herbert Simon and many others have indicated that the capacity of the human mind for formulating, analysis and interpretation of complex large scale issues is very small compared with the size and scope of the issues whose resolution is required for objective, substantive, and procedurally rational behavior. Anthony Downs * has also indicated that decision quality is considerably limited by the human intellect. Among the limits to rationality cited by Downs are:

1) Each decisionmaker can formulate, analyze, and interpret only a restricted amount of information
2) Each decision maker can devote only a limited amount of time to decision making
3) Most decision maker's become involved in many more activities than they can consider and completely cope with simultaneously; thus they must necessarily focus attention only on a portion of their major competing concerns.

The direct effect of these is the presence of cognitive bias in information acquisition and processing and the use of cognitive heuristics for evaluation of alternatives. There are many cognitive biases prevalent in most information acquisition activities. The use of cognitive heuristics and decision rules is also very prevalent. One such heuristic is satisficing or searching

*Downs, Anthony, Inside Bureaucracy, Little Brown and Company, Boston, 1967.

for a solution that is "good enough." This may be quite appropriate if the stakes are small. In general, the quality of cognitive heuristics will be very task dependent, and often the use of heuristics for evaluation will be both reasonable and appropriate. Rational decision making requires time, skill, wisdom and other resources. It must, therefore, be reserved for the more important decisions. A goal of systems engineering is to enhance information acquisition, processing, and evaluation such that efficient and effective use of information is made in a process that is symbiotic to the cognitive style and time constraints of management.

Planning and decision support process design must be responsive to several viewpoints concerning choicemaking. These include:

1) economic rationality - which assumes that the most important option alternatives are identified and evaluated with the best being selected.

2) satisficing or process oriented bounded rationality - bounded rationality allows only a relatively limited formulation, analysis, and interpretation and reliance on cognitive heuristics to obtain a "good enough" alternative that satisfies aspirations.

3) organizational procedures - here, the emphasis is on organizational structures, interrelationships, and communication and coordination among different units of an organization. This is a viewpoint which encourages use of standard operating procedures.

4) bureaucratic politics, incremented, or "muddling through" viewpoint- This regards participants in planning and decision making as actors who have strong individual preferences and vested interests. These

actors form bargaining coalitions. Consequently, innovations are generally resisted by those subgroups that will be adversely affected and incremental deviations only are possible.

Also, we need to recognize that individuals will vary in the cognitive complexity they will associate with a given decision situation. Individuals vary in their experiences, cognitive styles, problem solving abilities, and information processing behavior.

Systemic process design must be responsive to the observation of cognitive psychologists that there are two fundamentally different through or cognition processes. These are often associated with different halves of the brain. One type of thought process is described by the adjectives:

. verbal

. logical

. sequenced

. thinking

. analytical,

whereas the second is described as:

. nonverbal

. intuitive

. holistic

. feeling

. heuristic

The verbal process is typically viewed as superior in engineering and natural science. But this viewpoint on the nature of thought is false and should be strongly discouraged as positively harmful. For, the two

processes are complementary and compatible. They are not competitive and incompatible in any meaningful way. One thought process may be deficient, in fact, if it is not supported by the others. The nonverbal supports the verbal by suggesting ideas, alternatives, etc. The verbal supports the nonverbal by expressing, structuring, analyzing and validating the creative ideas that occur in the nonverbal process. An appropriate planning and decision support process must provide for verbal and nonverbal support. An appropriate planning and decision support process must be tolerant and supportive of decisionmaker cognitive (thought) processes, which will typically vary across individuals and within the same individual as a function of the environment, the individuals previous experience with the environment, and those factors which introduce stress. Thus a contingency task structural view of individuals and organizations in decision situations is needed; as contrasted with a stereotypical view in which individuals are assumed to process fixed static unchanging cognitive characteristics uninfluenced by environmental considerations.

Typically, we learn from experience and adopt various decision rules in the form of cognitive heuristics based upon this experience. The strength of belief that we have in the usefulness of heuristics is often based on reinforcement through feedback. Often this is such as to reinforce the use of various types of lexicographic semiorders that lead to intransitive choices; intransitive choices which often are not recognized. We often convince ourselves to like what we get from a decision and, since we often define issues by content rather than by structure, find it hard to separate decisions from outcomes in retrospective evaluation of our judgments. Much of this is probably due to abilities to change attitudes and perceptions without being

aware of the change, and to change our forecasts,retrospectively, to correspond to events that have occurred without recognizing this.

We are most likely to have coherent value preferences and are able to develop and utilize appropriate evaluation heuristics in well structured situations,that we are familiar with. Learning by trial and error and development of judgment based upon either reasoning by analogy, standard operating procedures, or organizational rules, typically results from these "concrete operational" situations. Long standing use of these "rules" results in purely affective judgment and decision responses. In a familiar and simple world, a "concrete operational" world, these judgment guides and judgment heuristics might well be, and in fact often are, quite acceptable. In a changing and uncertain environment that is different from the one with which we are familiar, we may well err considerably by using these judgment heuristics. If we do not have developed coherent values relative to a changing environment, we may respond affectively with the first alternative option that comes to mind. We may well adopt post decision behavior such as to maintain a chosen response and employ cognitive biases and cognitive heuristics to justify this potentially ill chosen response. This results in an affective response, appropriate for a "concrete operational" situation when an analytical response, appropriate for a "formal operational" situation, is needed.

A serious problem in practice, is that we get used to very simple heuristics that are appropriate for "concrete operational" situations in a familiar world and we continue to use them in "formal operational" situations in an unfamiliar world in which they may be very inappropriate. A typical heuristic is incrementalism: "Go ahead and crowd one more beast into the commons". Such a heuristic may be appropriate in the familiar situation our forbearers encountered in a new unexplored continent. But the "social traps" produced by such judgmental heuristics in a now crowded environment may be inappropriate.

There are numerous contemporary issues to support this assertion.

Inadequate analysis, and information acquisition and processing models resulting in a poor decision situation model may also occur due to poor experiential learning. Anthony Downs* has indicated 3 bounded rationality limits to modeling that directly affect information acquisition, processing, and evaluation:

1) the amount of information initially available is only a very small fraction of that potentially available
2) the "costs" of procurement of additional information, processing and use of this additional information may be high
3) important information, especially concerning future events, is often unavailable.

Thus, uncertainty is a major factor inherent in any realistic situation in which information costs are present.

Stress is the major determinant incluencing our coping patterns with respect to decision making**. Stress, in turn, is determined by time available, uncertainties, structure of the decision situation and the decisionmaker's awareness of this structure, and the hope of generating appropriate alternatives. Finally, value perceptions affect the entire systems process. A number of questions may be posed with respect to formulation, analysis, and interpretation that clearly indicate the role of values in every portion of a systems engineering effort. Issue formulation questions of importance in this regard are:

*Downs, Anthony, Op. Cit.

**Janis, I., and Mann, L., Decision Making, Free Press, 1977.

- What is the problem? The needs? The constraints? The alterables?
- How do the client and the analyst bound the issue?
- What objectives are to be fulfilled?
- What alternative options are appropriate?
- How are the alternatives described?
- What alternative state of nature scenarios are relevant to the issue?

Analysis questions of importance are:

- How are pertinent state variables selected?
- How is the issue formulation disaggregated for analysis?
- What generic outcomes or impacts are relevant?
- How are outcomes or impacts described across various societal sectors?
- How are uncertainties described?
- How are ambiguities described?
- How are questions of planning period and planning horizon dealt with?

Interpretation concerns with respect to value influence are:

- How are values and attributes disaggregated and structured?
- Does value and attribute structuring and associated elicitation augment or replace intuitive affect?
- How are cognitive heuristics and cognitive biases dealt with?
- Are value perspectives altered by the systemic aiding process?

Finally, how is total issue resolution time divided between formulation, analysis and interpretation? For the allocation of resources to various systemic activities may reflect a number of value perspectives of the analyst and the client. Clearly all of this has strong implications for guidelines to professional practice.

A central goal of systems engineering is solving problems with clients through brokerage, facilitation, and communication. To accomplish this, it appears necessary that we first must understand and then be able to express an understanding of clients and stakeholders of:

a) cognitive heuristics and their potential limitations

b) cognitive biases and procedures to detect and ameliorate their effects

c) ways to cope with value incoherences such as to create coherence

d) rational decision rules

e) a variety of perspectives on rationality

As a minimum, this appears to require an understanding of psychology, philosophy, economics, and sociology as well as appropriate understanding of technology; and (of course) systems methodology and systems engineering.

Substantive and procedural rationality are each needed to effect appropriately designed systemic process adjuvants. Cognitive limitations in systems engineering in general, and decisionmaking in particular are due primarily to the presence of five related factors:

1) bounded rationality in formulating issues and identifying decision situation structural models

2) cognitive bias in information acquisition and processing

3) value inconsistencies and incoherencies

4) judgmental heuristics in decision rule selection

5) contingency task structure and the effects of the environment and decision maker experience.

Essentially all modern views indicate that humans are sequential selective issue formulation and information processors, affected by cognitive biases of various types, who utilize a number of different decision rules and

evaluation heuristics that depend upon the contingency task structure of the environment, and the performance objectives or aspiration level associated with the task.

Bounded rationality views of human problem solving and choicemaking suggest that decisionmakers construct a simplified model of the world, and select an aspiration level to determine what they would like to get in terms of what they think they can get. Next, they identify and process information concerning aspects of alternatives until they find one which exceeds their aspiration level. Aspiration levels are adaptively adjusted in time in accordance with results obtained and other prior experiences. The potentially available information set is determined by the contingency task structure and personal characteristics, including experience, of the decision maker. A satisficing choice will often result from this process with modest effort. But, the decision maker foregoes the possibility of identifying, evaluating and selecting outstanding or "best" alternatives. Doubtlessly this is appropriate for minor decisions, or those of a "concrete operational" tactical nature. But for major decisions with significant impacts, such as those of a strategic nature or with "formal operational" requirements, the approach is normatively questionable.

Yet, there is much value in satisficing type models of human behavior. Our discussion in the sequel will indicate the vital role that satisficing type models should play in the design of information systems for planning and decision support. For, one of the purposes of decision support is to develop appropriate heuristics for "concrete operational" structured efforts on the basis of experience gained in "formal operational" and unstructured efforts.

There are two primary ways in which we provide descriptions of human efforts:

Descriptive - discover, by experiment and observation, how humans perform in particular situations

Normative (prescriptive) - discovery, typically by means of rational theoretical postulates, of what one should do.

Both descriptive and normative theories are needed to provide a useful approach and framework, for understanding and design, of systemic support systems. We should note that bounded rationality, cognitive bias, judgmental heuristics, and value inconsistencies each may result, under certain circumstances, in irrational and inappropriate behavior. All of these result from, as well as produce, very problem dependent symptoms. It is difficult to imagine a theory which will predict procedurally or substantively acceptable behavior, in either a descriptive or normative sense, in any specific circumstance. Prospect theory developed by Kahneman and Tversky, * appears to be the best available substantively acceptable descriptive theory; but different application of the "editing" rules for prospect theory will result in different procedural rules.
Current efforts at extension of this theory may, and hopefully will, result in procedural and substantive, descriptive and normative, guidelines for information system

Insights into the nature of intellectual development and insights into a conceptual model of cognitive activity is contained in the works of Piaget ** , the founder of "genetic epistemology". According to Piaget, there are four stages of intellectual development:

1) sensory motor
2) preoperational
3) concrete operational
4) formal operational

* Kahneman, D., and Tversky, A., "Prospect Theory: An Analysis of Decision Under Risk", Econometrica, vol. 47, March 1979, pp. 263-291.

** Inhelder, B. and Piaget, J., The Growth of Logical Thinking, Basic Books, NY, 1958.

The last two of these are of importance to our efforts here. In the writings of Piaget, intellectual development is a function of four variables:

1) maturation
2) experience
3) education
4) self regulation - a process of mental struggle with discomforting information until identification of a satisfactory mental construction allows intellectual equilibrium. The result is intellectual growth or learning.

Concrete operational thinkers can deal logically with empirical data, manipulate symbols, and organize facts towards the solution of certain problems. Formal operational thinkers can cope in this fashion also. A major difference, however, is that concrete thinkers lack the capacity to reason hypothetically and consider the effects of different variables or possibilities outside of personal experience. Thus concrete operational thinkers will often have difficulty in responding true or false to the statement, "six is not equal to three plus four." If we pose the hypothesis: a card with a vowel on one side will have an even number on the other side, then concrete operational thinkers will have difficulty selecting cards for bottom side examination if the top sides of four cards with letters on one side and numbers on the other are a, b, 2, 3. However, failure to pick the cards with a and 3 on top may not indicate inability as a formal operational thinker but, rather, a failure to properly diagnose the task and determine the need for formal operational thought. We see again, the dominant role of the contingency task structure in guiding problem solving efforts. In concrete operational thought, people use concepts which are:

1) drawn directly from their personal experiences

2) involve elementary classification and generalization concerning tangible and familiar objects

3) involve direct cause and effect relationships; typically in simple two variable situations

4) can be taught or understood by analogy, algorithms, affect, standard operating policy, or receipe

5) that are "closed" in the sense of not demanding exploration of possibilities outside of the known environment of the person and stated data

In formal operational thought, people use concepts which may:

1) be imaged, hypothetical, based on alternative scenarios, and/or which may be contrary to fact

2) be "open ended" in the sense of requiring speculation about unstated possibilities

3) require deductive reasoning using unverified and perhaps flawed hypotheses

4) require definition by means of other concepts or abstractions that may have little or no obvious correlation to contemporary reality

5) require the identification and structuring of intermediate concepts not initially specified

Formal operational thought involves three stages:

1) reversal of realities and possibilities

2) hypothetico deductive reasoning

3) operations on operations

as shown in Figure 8. These are typically accomplished through reflective observation, abstract conceptualization and the testing of the resulting concept implications in new situations. It is in this way that the divergence produced by discomforting new experiences allows the learning of new developments and concepts to be "stored" as part of ones concrete operational experiences.

Styles or modes of information acquisition and information evaluation appear to be of primary importance in the design of information systems for interpretation of the impacts of proposed policy. Information acquisition refers to the perceptual process by which the mind organizes the verbal and visual stimuli that it encounters. McKenney and Keen* discuss two modes of information acquisition, a preceptive mode and a receptive mode:

a) In preceptive acquisition, individuals bring formal concepts and precepts to bear to filter data. They focus on structural relations between items and look for deviations from their expectations. They use then formal precepts as cues for acquisition and structuring of data.

b) In receptive acquisition, individuals focus on contextual detail rather than relationships and derive attributes from direct examination rather than from fitting it to their precepts.

There is nothing inherently good or bad in either mode of information acquisition and structuring. The same individual may use different modes as a function of contingency task structure, but most people will have preferences for one mode or the other. It is our hypothesis that cognitive biases often arise, or are initiated, by use of a situationally incorrect mode of information acquisition and structuring.

*McKeeney and P. G. W. Keen "How Managers' Minds Work" Harvard Business Review, May-June, 1974, pp. 79-90.

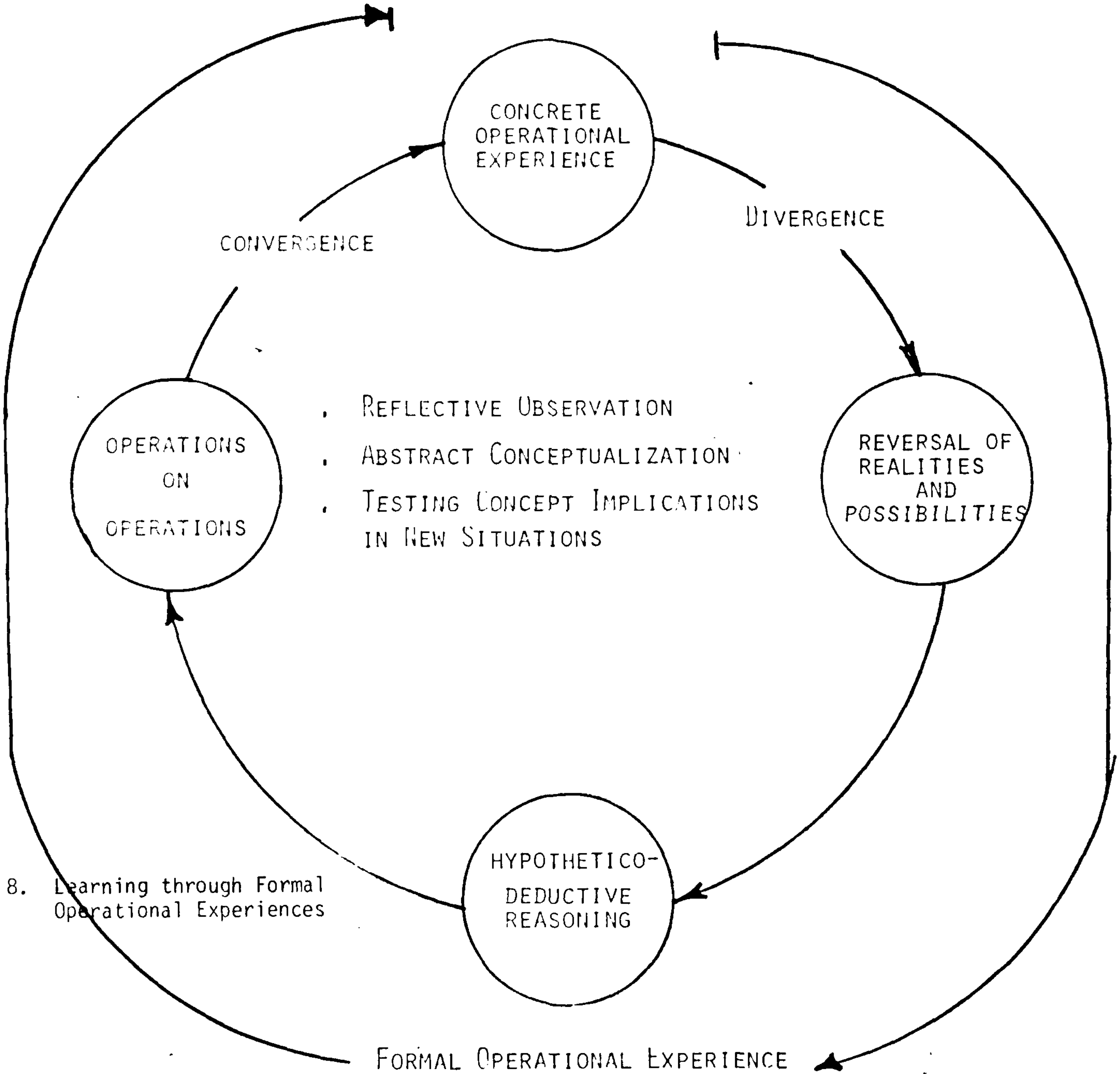


Figure 8. Learning through Formal Operational Experiences

Information evaluation refers to the process of problem solution. We advocate use of the Piaget model of concrete and formal operational thinking as a useful precept for information evaluation and associated information system design.

a) In concrete operational thought, individuals approach problems either through intuitive affect; or through following a standard operating policy or organizational processes

b) In formal operational thought, individuals approach problems through structuring in terms of imbedding realities into possibility scenarios, hypothetico-deductive reasoning, and interpretation in terms of operations on operations.

Figure 9 presents our conceptualization of information acquisition and evaluation, or problem solving styles. Again we argue that no style is inherently appropriate or inappropriate. Appropriateness of a particular style is very much task, environment, and experience dependent. That most decisionmakers, or humans for that matter, would prefer to function as concrete operational thinkers, is doubtlessly correct. A principal task of a well designed information system is to assist in detecting the appropriate style for a given task, environment, and decisionmaker experience level and to enhance transfer of formal operational experiences to concrete operational experiences, such as through conceptualization of appropriate heuristics, analogous reasoning guides, standard operating procedures, and even condtioning of affective thought or precognitive response. Figure 9 also shows typical decision rules for various concrete operational evaluation modes. As indicated, we posit that both types of information acquisition should occur with each of these styles, although the balance of receptive and preceptive acquisition will vary from decision rule to decision rule.

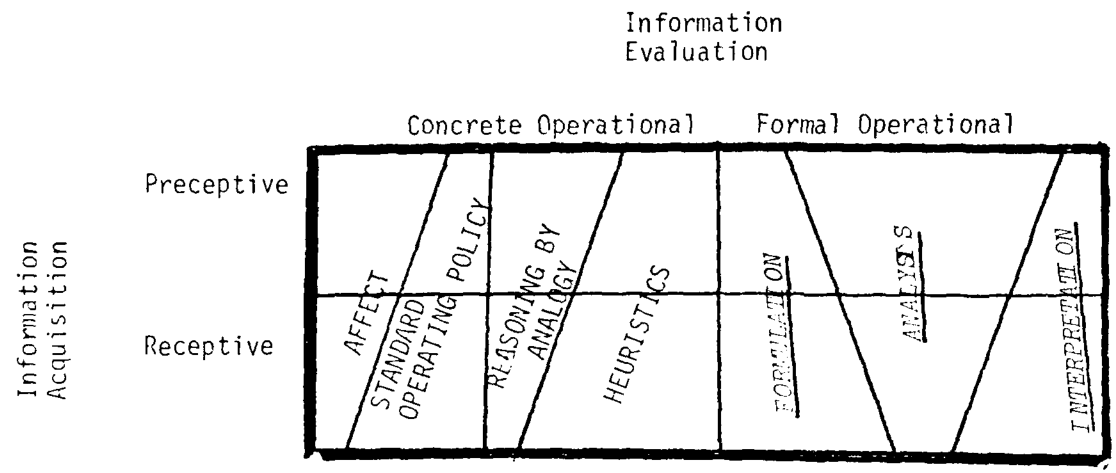


Figure 9. Conceptualization of Problem Solving Styles

Our discussions have indicated the strong environmental dependence of the process of formulation analysis and interpretation. It is the interaction of the environment with an organization and a technology that results in a management technology. Systems management is the term we use to denote the interaction of human judgment with methodological concerns. Systems management denotes, therefore, concerns at the cognitive process level that involve the contingency task structure and its role in influencing the selection of performance objectives and decision rules for evaluation of options associated with issue resolution. Figure 6 has indicated some of the influences on the contingency task structure and Figure 10 indicates how the contingency task structure, and the environment which influences it, acts to specify and direct problem solving efforts.

It is our belief that the cognitive style model of Figure 9 can be used as a guide to illustrate both the likely modes of information acquisition and information evaluation that should be used, and that will be used, on a given issue. We stress that the particular cognitive style most appropriate for a given issue will depend upon the decisionmakers experience with a given issue, the issue itself, and the environment into which the issue is imbedded. Thus a receptive or preceptive information acquisition style will be appropriate in a formal operational setting if the issue at hand is an unfamiliar one. The balance between preceptive and receptive information acquisition will be dependent upon the personal style of the decisionmaker and the type of interaction with the systems analyst as well as upon the type of information evaluation (formulation, analysis, or interpretation) being attempted.

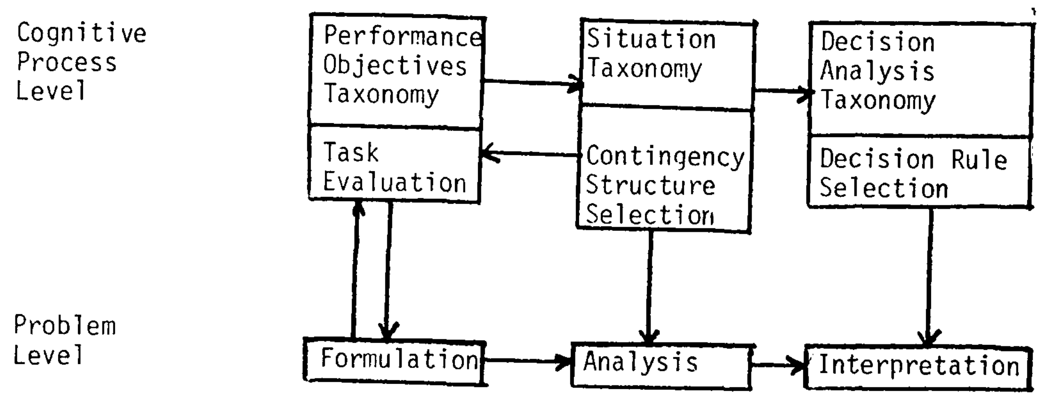


Figure 10. The Role of Systems Management in Determining Specific Problem Solving Approaches

Proper systems management is essential for the design of useful systemic processes. There are a number of concerns relative to this. To design algorithms, such that they possess not only internal integrity, but also that the combination of algorithms results in a methodology for propitious issue resolution, represents a challenge that has not yet been met. To accomplish this to full satisfaction, it is also necessary to recognize the fundamentally different nature of the approach of the policy and decisionmaker and the systems or policy analyst. The goal of the former is problem amelioration, which appears to be that of conflict resolution or issue disposal, in such a manner so as to achieve acceptable equilibrium among conflicting objectives of stakeholder groups concerning social justice, economic efficiency, and individual freedom. The goals of policy and systems analysts are much more those of intellectual design, mastery, understanding, and management of complex issues. There is no essential conflict between the upper level goals of the two groups and natural tensions between the two professions, public and private sector management and systems analysts, could be exploited for greater symbiosis. To accomplish this for the betterment of both groups, it seems necessary to explicitly recognize and incorporate, into the systems process, and the policy and decisionmaking process, three features often neglected:

1. Situation models of the role of diverse actors in policy and decisionmaking processes
2. A general understanding of the diversity of behavioral and quantitative algorithms available and their role in the steps of the systems process

3. Input-Output linkages to connect the various steps in the systems process and allow integration of these steps to produce unified coherent results concerning the issue under consideration.

4. Implications for Systems Engineering Education and Professional Practice

There are a number of characteristics of systems engineering that are of special interest with respect to their implications for education, and professional practice. It is apparent that systems engineering is, and should be, highly varied in its approach to problems. One characteristic that is common to all systems engineering efforts, is that systems engineers render professional staff assistance to clients. As a consequence, success of systems engineering efforts can be measured in terms of this potential assistance. As we have indicated, the systems engineering profession is one which involves:

1) formulation, analysis, and interpretation and
2) the delivery of information and advice based upon performance of these functions

This second activity is especially important and leads to our assertion that systems engineering is solving problems, not only for clients, but with clients. Thus abilities as a facilitator, broker, and communicator of knowledge are especially important ones for systems engineers. The values, cognitive styles, educational backgrounds, external and internal incentives, and standards of accomplishment may differ considerably across client groups. This, also, imposes many challenges for the successful practice of systems engineering.

Those in systems engineering practice make use of the three functional abilities skills or attributes of systems engineering in varying amounts depending upon the task, the client for the effort, and the characteristics of the systems engineering professional.

We might denote an "analyst" as one who emphasizes primarily the systems science and operations research tools in their efforts to aid clients. A person who uses methodological design considerations coupled with systems management considerations in their approach to problems might be denoted an "organizer". An "entrepreneur" is one who has considerable systems management skill , and skills with respect to a limited set of systems science and operations research tools. A "skilled analyst" is one with a broad knowledge of the methods of systems science and operations research and a sound knowledge of systems methodology and design, but who does not strongly emphasize systems management considerations. Finally, a "skilled systems engineering innovator" is one who combines a sound knowledge of all three of these functions. Table 2 illustrates characteristics and attributes likely to be associated with systems engineering practiced by individuals with these characteristics. Clearly, we strongly encourage development and possession of all three functional skills, to the extent possible, in all systems engineers, and surely in a systems engineering team. Figure 3 illustrates the complete set of functional skills for systems engineering and their components and now we have provided justification for the inclusion of these three "functions" within systems engineering.

Most contemporary large scale issues in the private and public sectors require a systemic approach for resolution. Many realities confirm this. Stakeholders to a decision process typically cannot intuitively evaluate and interpret plans, programs, or action alternatives in terms of objectives. Plans programs and alternatives, which serve as inputs to a large scale system, must be translated into impacts before they can be evaluated. Interpretation, in terms of values, follows from the analysis of an issue formulation which

TABLE 2. CHARACTERISTICS AND ATTRIBUTES OF SYSTEMS ENGINEERING EFFORTS

CLASSIFICATION OF PERSON AND/OR RESEARCH	MAJOR INCENTIVE AND MOTIVATION	PRIMARY RESOURCES USED	ATTITUDE TOWARDS CLIENTS	STANDARD OF SUCCESS
ORGANIZER	MANAGEMENT OF A SYSTEMS TEAM; PERSONAL INFLUENCE	BROKERAGE, COMMUNICATION, AND FACILITATION SKILLS	SERVICE; OCCASSIONALLY ANALYSIS IS USED AS A DEVICE TO ENHANCE PERSONAL INFLUENCE	A SATISFIED CLIENT
ANALYST	OPPORTUNITY TO DO RESEARCH IN ANALYSIS	SOURCE OF DETAILED KNOWLEDGE OF (TYPICALLY) A FEW SPECIALIZED TECHNIQUES	OBJECTIVE; OFTEN REFUSES TO CONSIDER THE SUBJECTIVE, AND VIEWS ANALYSIS AS AN END IN ITSELF AND NOT THE MEANS TO AN END	EFFORT PERCEIVED BY THE ANALYST AND THE ANALYST'S PEERS AS BEING OF HIGH QUALITY
ENTREPRENEUR	PROBLEM RESOLUTION, OFTEN USING A RESTRICTED SET OF ANALYSIS TOOLS	KNOWLEDGE OF SELECTED METHODS PLUS BROKERAGE AND COMMUNICATION SKILLS	ANALYSIS AS A MEANS FOR SERVICE TO CLIENTS, OFTEN WITH A RESTRICTED SET OF TOOLS	ISSUE RESOLUTION
SKILLED ANALYST	OPPORTUNITY TO DO BROAD SCOPE RESEARCH IN ANALYSIS AND DESIGN	SOURCE OF BROAD BASED KNOWLEDGE	ANALYSIS AS AN END IN ITSELF	EFFORT PERCEIVED BY THE ANALYST AND THE ANALYST'S PEERS AS BEING OF HIGH QUALITY
SKILLED SYSTEMS ENGINEERING INNOVATOR	BROAD SCOPE PROBLEM RESOLUTION	SOURCE OF BROAD BASED KNOWLEDGE PLUS BROKERAGE, COMMUNICATION AND FACILITATION SKILLS	ANALYSIS AS A MEANS FOR SERVICE IN WORKING WITH CLIENTS	ISSUE RESOLUTION AND CLIENT SATISFACTION

includes values and alternatives. As a consequence, stakeholders to a decision process must have knowledge of the system dynamics or production functions which translates inputs into outputs. Thus some method which allows formulation, analysis, and interpretation of large scale issues; and the involvement of relevant stakeholder groups, through facilitation, brokerage and communication, in acquisition and understanding of this "knowledge"; must be provided. Without this; the advocacy, bargaining, negotiation, and compromise process will not allow a meaningful interpretation of values that is needed in order to result in appropriate and useful decisions. Obviously, this represents a major, presently unmet, challenge.

While technical experts are necessary for large scale issue resolution, issues cannot be identified and valuated <u>only</u> by elicitations from technical experts; there are many perspectives to consider. Systems engineering practioners recognize that:

1) means and ends are very closely interconnected
2) facts and values are difficult to separate, and the separation of these is a central thesis of systems engineering efforts

Further, we recognize that we determine the way in which means influence ends through analysis. Again, the systems engineering process involves communications, brokerage, and facilitation between parties at interest. This, together with analysis, allows the clarification of value judgments which will lead to revised value judgments that serve also to guide specific applications of the systems engineering process.

Systems engineering allows for an essential and substantial contribution

to the private and public sector policy process by identification and structuring of linkages between alternative policy options and values. This is accomplished by the determination of the impacts of proposed policy alternatives through "analysis" and the evaluation of these impacts through "interpretation". Consequently, a central goal of systems engineering is analysis such as to enable separation of relevant issues from the irrelevant. By this, and by separation of facts and values, investigation efforts and associated debate are channeled in ways such as to insure the maximum return from a given resource investment. This is another of the primary objectives of systems engineering.

We strongly believe that technoeconomic efficiency does not produce virtue but, ignorance of resource constraints does not produce virtue either. Nor does virtue necessarily produce efficiency.

And so the use of systems engineering introduces a new set of actors into the decisionmaking process. We see again the inevitable need for tradeoffs among noncommensurate objectives and attributes, the determination of which is a central feature of the systems engineering approach.

If systems engineering is to remain useful as a management adjuvant for public and private sector decisionmaking, it must become and must remain imbedded in the political process of management and it must modify the management process for the better. At each level of management and decision processes systems engineering nominally then becomes an adjuvant to enhanced efficiency, effectiveness and equity.

5. Conclusions

There are a number of effectiveness attributes or aspects of effective systemic processes. Design of an effective systemic process necessarily involves integration of operational environment concerns involving human behavior and judgment with methodological concerns. An effective systemic process should:

1) Allow a very thorough and carefully conducted requirements specification effort to determine and specify needs of stakeholders prior to conceptual design of a process to accomplish the desired task,
2) Be capable of dealing with both quantitative and qualitative criteria representing costs and effectiveness from their economic, social, environmental and other perspectives,
3) Be capable of minimizing opportunities for cognitive bias, and provide debiasing procedures for those biases that occur,
4) Allow separation of opinions and facts from values; and separation of ends from means, or values from alternative acts,
5) Provide an objective communicable framework that allows identification, formulation, and display of the structure of the issue under consideration, as well as the rational of the choice process.
6) Allow for considerations of tradeoffs among conflicting and incommensurate criteria,

7) Provide flexibility and monitoring support to allow evaluation rule selection with due consideration to the task structure and operational environment constraints on the decisionmaker.

8) Provide an open process to allow consideration of new criteria and alternatives as values change and broadscope awareness of issues grows.

There are a number of potential benefits of the systems approach which should follow from high achievement of each of the criteria for effective systemic processes. An appropriate systemic process design will:

1) Provide structure to relatively unstructured issues
2) Facilitate conceptual formulation of issues
3) Provide cognitive cues to search and discovery
4) Encourage parsimonious collection, organization, and utilization of relevant data
5) Extend and debias information processing abilities
6) Encourage vigilant cognitive style
7) Provide brokerage between parties at interest

There are many imperfections and limits to processes designed using the methodologies from what we know as systems engineering and systems analysis. Some of these have been documented in this essay. But what are the alternatives to appropriate systemic processes for the resolution of complex large scale issues; and are not the fundamental limitations to these alternatives even greater?

References

This paper has presented a somewhat personal interpretation of systems engineering. The references cited, while also personal, contain many references to other original source documents.

General discussions of systems engineering, including many systems science and operations research methods, can be found in:

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